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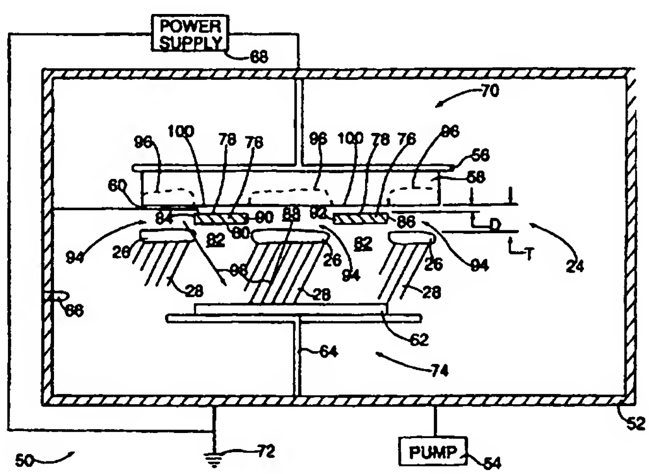
(54) Title: METHOD AND APPARATUS FOR RF DIODE SPUTTERING



(57) Abstract

A sputtering system (50) includes an evacuatable chamber (52) having a target (58) which includes a sputtering surface (60). The target (58) is biased to form a cathode element (70) which causes the emission of electrons. The system (50) further includes an anode element (74) which includes the substrate (62). In use, a sputtering gas is ionized in response to the electrons to form a plasma. The plasma includes a cathode dark space (24) having a first thickness (T) wherein ionization does not occur. A plate element (76) having a bottom surface (80) is positioned a first distance (D) from the sputtering surface (60). Electrons emitted from the target (58) are absorbed by the plate element (76) to inhibit plasma formation in a first area (82) adjacent the bottom surface (60) such that target material (58) is not eroded opposite the first area (82). Further, plasma is formed in a second area (94) adjacent an edge (84, 86, 90, 92) to cause target material (58) to be eroded from the second area (94).

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METHOD AND APPARATUS FOR RF DIODE SPUTTERING

FIELD OF THE INVENTION

This invention relates to RF diode sputtering, and more particularly, to a plate positioned within a cathode dark space which serves to selectively inhibit plasma formation in order to be able to selectively erode areas of a sputtering surface to provide a desired non-uniform erosion pattern for improving thickness uniformity for a film formed on a substrate.

BACKGROUND OF THE INVENTION

An integrated circuit (IC) is manufactured by a process which utilizes planar technology. Generally, this process includes subjecting a substrate, such as a silicon wafer or a ceramic plate, to a sputtering process in which a thin layer or film of material is deposited on the substrate. A common type of sputtering is known as magnetron sputtering. In this type of sputtering, a sputter deposition system is used which includes a chamber having a sputtering target. The target is fabricated from a desired source material and includes a sputtering surface from which material is removed for forming the film. In operation, a substrate which is to be sputtered is positioned within the chamber opposite the sputtering surface. A process gas, such as argon, is introduced into the chamber between the sputtering surface and the substrate. The target is then negatively energized so as to cause electrons to be emitted from the target. The electrons strike and ionize the gas particles to cause the formation of a plasma having positively charged argon ions. The ions then bombard the sputtering surface, which causes the removal of target material. The removed target material is then ultimately deposited onto the substrate to form the film.

A magnetic field for confining and shaping the plasma into a desired configuration is positioned near the sputtering surface. In particular, the plasma is shaped such that a desired non-uniform pattern of erosion is formed on the sputtering surface. This serves to ensure that all areas of the substrate receive substantially equal amounts of sputtered material, thus enabling a substantially uniform film thickness to be formed on the substrate

In an alternative form of sputtering, which is known as radio frequency (RF) diode sputtering, a magnetic field is not utilized to confine or shape the plasma. This type of sputtering

is frequently used for the sputtering of electrically insulating target materials, and for sputtering targets of magnetic material. In addition, RF diode sputtering is also used where the presence of magnetic fields generated by the sputtering cathode may undesirably affect properties of the deposited film. However, since a magnetic field is not used to confine and shape the plasma in RF diode sputtering, the erosion pattern of the sputtering surface cannot be controlled as desired. As a result, an undesirable uniform erosion pattern forms on the sputtering surface which results in the formation of a film thickness that is not uniform. Further, reduced deposition occurs near the substrate edge due to the shape of the plasma, which also undesirably affects film thickness uniformity.

Referring now to FIGURE 1, an illustrative depiction of a plasma 10 is shown located between a target 12 having an initial sputtering surface 14 and a substrate 18 which is supported by support 16. The plasma 10 includes several different functional zones which are formed during the sputtering process. In use, the target 12 is negatively energized and the support 16 is grounded to form a cathode element 20 and an anode element 22, respectively. This causes electrons to be emitted from the target 12 which travel through a cathode dark space 24 and then collide with gas molecules to cause the formation of ions in a negative glow area 26 and a positive column 28. In the cathode dark space 24, ionization does not occur since the emitted electrons typically do not possess sufficient energy. Further, the cathode dark space 24 has a thickness T which depends primarily on the voltage applied to the target 12 and the type and pressure of the sputtering gas utilized. The ions are then accelerated towards cathode element 20 by a high voltage gradient across the cathode dark space 24.

A device known as a dark space shield 30 is located adjacent to a rear surface 32 of the target 12. The shield 30 is spaced apart from the rear surface 32 by a distance X which is less than thickness T. As such, the shield 30 is located in a region where ionization does not occur. The shield 30 is connected to ground 34 and serves to absorb electrons which are emitted, thus inhibiting the formation of plasma adjacent the rear surface 32. The shield 30 is utilized in configurations wherein sputtering on the rear surface 32 is not desired such as when a structural backing plate is used to support the cathode element 20. For plasmas which are not magnetically confined, thickness T is typically between approximately 0.25 to 0.75 inches under commonly used sputtering conditions.

One method of improving film thickness uniformity in RF diode sputtering is to increase the size of the target 12 relative to the substrate 18. This has been found to reduce the effect of reduced deposition near the substrate edge. However, a disadvantage of this method is that larger and more costly targets are needed. This results in the need for correspondingly larger processing chambers to hold the targets and larger power supplies to energize the targets, which also increases costs. Moreover, the use of larger targets results in reduced utilization of target material.

Another method for improving film thickness uniformity includes the positioning of an object, such as an aperture plate, between the target and substrate. The aperture plate serves to intercept a percentage of sputtered material to prevent its deposition on the substrate. This method is described in U. S. Patent No. 5,415,753, which issued to Hurwitt, et al. and is assigned to Materials Research Corporation, an assignee herein. Referring to FIGURE 2, an illustrative cross sectional view of a portion of an aperture plate 36 having an aperture 38 in accordance with U.S. Patent No. 5,415,753 is shown. The aperture plate 36 is located between the target 12 and the substrate 18 which is to be sputtered. In RF diode sputtering, wherein a magnetic field is not used to control the plasma, the initial sputtering surface 14 is eroded in an undesirable uniform pattern to form a new sputtering surface 40 (shown as dashed lines) which is generally flat and parallel to the initial sputtering surface 14. The design of the aperture plate 36 and its spacing from target 12 and substrate 18 is calculated so as to intercept controlled amounts of material emitted from target 12. In particular, a portion of sputtered material (illustrated by arrow 42 which depicts a flight path of a first particle) emitted from the target 12 passes through or around the aperture plate 36 and is deposited on substrate 18. Another portion of sputtered material (illustrated by arrow 44 which depicts a flight path of a second particle) is intercepted by the aperture plate 36 and forms a deposit 46 on the aperture plate 36. As such, this technique improves thickness uniformity by intercepting material emitted from target 12 and not by controlling the shape of the plasma.

However, this technique has disadvantages. One disadvantage is that extended spacing is needed between target 12 and substrate 18 to permit proper placing of target 12 to avoid a shadow of the aperture plate 36 from forming in the deposited film Another disadvantage is that

as more material is sputtered, the deposit 46 increases in size and forms flakes or microscopic particles which fall on or become imbedded in the film that is formed on the substrate.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a sputtering system for improving thickness uniformity of a film sputtered on a substrate.

It is a further object of the present invention to selectively inhibit the formation of plasma by absorbing electrons emitted from a target in order to provide a desired non-uniform erosion pattern suitable for improving film thickness uniformity.

The present invention relates to a sputtering system for depositing a thin film on a substrate. In particular, the system includes an evacuatable chamber having a target The target includes a sputtering surface which is biased to form a cathode element which emits electrons. The system further includes an anode element which includes the substrate. The substrate is positioned opposite the cathode element in the chamber. In use, a sputtering gas is ionized in response to the electrons to form a plasma for eroding target material from the sputtering surface which is then deposited on the substrate to form the film In addition, the plasma includes a cathode dark space having a first thickness wherein ionization does not occur.

A plate element having a bottom surface and at least one edge is positioned a first distance, which is less than the first thickness, from the sputtering surface. Electrons emitted from the target are absorbed by the plate element so as to selectively inhibit plasma formation in a first area adjacent the bottom surface such that target material is not eroded from a predetermined first portion of the sputtering surface opposite the first area. Further, plasma is formed in a second area adjacent the edge to cause target material to be eroded from a predetermined second portion of the sputtering surface opposite the second area. This forms a desired non-uniform erosion pattern on the sputtering surface for improving thickness uniformity of the film.

BRIEF DESCRIPTION OF THE FIGURES

FIGURE 1 depicts a conventional plasma formed during a sputtering process.

FIGURE 2 is a cross section view of a portion of an aperture plate for intercepting material sputtered from a sputtering surface.

FIGURE 3 depicts a sputtering system having a plate element positioned within a cathode dark space in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

While this invention is susceptible of embodiment in many different forms, there is shown in the drawings and will herein be described in detail specific embodiments, with the understanding that the present disclosure is to be considered as an example of the principles of the invention and intended to limit the invention to the specific embodiments shown and described. In the description below, like reference numerals are used to describe the same, similar or corresponding parts in FIGURES 1-3.

Referring to FIGURE 3, a sputtering system 50 in accordance with the present invention is shown The system 50, which may be an RF diode sputtering system, includes a chamber 52 which is evacuated by a vacuum pump 54 to a vacuum level suitable for sputtering. The chamber 52 includes a target mounting element 56 for holding a target 58. The target 58 includes a sputtering surface 60 from which target material is removed, or sputtered, which is ultimately deposited on a substrate 62 to form a thin film. The system 50 further includes a support 64 for holding the substrate 62 in a position generally opposite the sputtering surface 60. In use, a sputtering gas, such as argon, is introduced into the chamber 52 through a nozzle 66. The target 58 is then negatively energized by a power supply 68 to cause an emission of electrons from the target 58, thus forming a cathode element 70. Further, the support 64 and substrate 62 are connected to ground 72, thus forming an anode element 74.

A plate element 76 (shown as a cross section) is positioned between the cathode 70 and anode 74 elements The plate element 76 includes a top surface 78 which is spaced apart from the sputtering surface 60 by a distance D which is less than thickness T. This serves to locate the plate element 76 within the cathode dark space 24. The plate element 76 further includes a bottom surface 80 which faces the substrate 62. The plate element 76 is connected to ground and thus serves to attract and absorb electrons which are emitted from the target 58 In accordance

with the present invention, this inhibits the formation of plasma in first areas 82 adjacent the bottom surface 80. Alternatively, it is noted that the plate element 76 and/or the substrate 62 may be subjected to a desired voltage by an alternate power supply rather than being connected to ground.

The plate element 76 further includes left 84 and right 86 outer vertical edges and a hole 88 which defines left 90 and right 92 inner vertical edges. In use, normal plasma formation occurs in second areas 94 which are adjacent the vertical edges 84, 86, 90, 92 and wherein electrons are not absorbed by plate element 76. As a result, first portions 96 of the sputtering surface which are directly opposite the second areas 94 are eroded. Some of the material removed from portions 96 (illustrated by arrow 98 which depicts flight paths of removed material) is then ultimately deposited on the substrate to form the film.

In accordance with the present invention, second portions 100 of the sputtering surface 60 which are opposite the first areas 82 do not erode due to the absence of plasma in these areas. This results in a desired non-uniform pattern of erosion on the sputtering surface 60 which provides a film on the substrate 62 having a substantially uniform thickness. Consequently, the present invention provides a uniform film thickness by selectively inhibiting the formation of plasma. In addition, since target material is not sputtered from second portions 100, the amount of target material that is accumulated on the top surface 78 is substantially reduced. Thus, contamination of the film due to the formation of flakes and particles on the top surface 78 is also substantially reduced.

The shape and dimensions of plate element 76 are each chosen to provide a desired erosion shape on target 58 which will produce a desired film profile on substrate 62. Several factors affect the configuration of plate element 76 such as the size of the target 56 and the substrate 62 and the distance between the target 58 and substrate 62. For typical sputtering conditions, it has been found that acceptable results are obtained when dimension D is between approximately 0.05 inch to 1.0 inch, wherein 1/8 to 3/8 of an inch is preferred. It is further noted that plate element 76 may also be configured in various other shapes and sizes so as to provide a desired film profile on substrate 62. For example, plate element 76 may be configured to include more than one hole. Alternatively, plate element 76 may be a solid plate. In addition, a series of concentric rings may be used in place of plate element 76

Thus it is apparent that in accordance with the present invention, an apparatus that fully satisfies the objectives, aims and advantages is set forth above. While the invention has been described in conjunction with specific embodiments, it is evident that many alternatives, modifications, permutations and variations will become apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended that the present invention embrace all such alternatives, modifications and variations are far within the scope of the appended claims.

What Is Claimed Is:

1 A sputtering system for depositing a thin film on a substrate, said system including an evacuatable chamber which includes said substrate, comprising:

a target positioned within said chamber, said target including a sputtering surface;

biasing means for biasing said target to form a cathode element which emits electrons;

an anode element which includes said substrate, wherein said substrate is positioned opposite said cathode element in said chamber;

ionization means for ionizing a sputtering gas, in response to said electrons, to form a plasma for eroding target material from said sputtering surface which is then deposited on said substrate to form said film, said plasma including a cathode dark space having a first thickness wherein ionization does not occur; and

a plate element having a bottom surface and at least one edge, said plate element being spaced apart from said sputtering surface by a first distance which is less than said first thickness, wherein electrons emitted from said target are absorbed by said plate element to selectively inhibit plasma formation in a first area adjacent said bottom surface such that target material is not eroded from a predetermined first portion of said sputtering surface opposite said first area, and wherein plasma is formed in a second area adjacent said edge to cause target material to be eroded from a predetermined second portion of said sputtering surface opposite said second area, thereby forming a desired non-uniform erosion pattern on said sputtering surface for improving thickness uniformity of said film.

2. The system according to claim 1, wherein said plate includes at least one hole for forming associated inner edges.

3. The system according to claim 1, wherein said plate element includes at least two concentric rings.

4 The system according to claim 1, wherein said plate element is a solid plate.

5. The system according to claim 1, wherein said plate element is maintained at a potential which is positive relative to said target.

6. The system according to claim 1, wherein said plate element is grounded.

7. The system according to claim 1, wherein said first distance is between approximately 0.05 and 1.0 inches.

8. A method for sputtering a thin film on a substrate, comprising the steps of.

biasing a target having a sputtering surface to form a cathode element which emits electrons,

providing an anode element which includes said substrate, wherein said substrate is positioned opposite said cathode element;

forming a plasma, in response to said electrons, for eroding target material from said sputtering surface which is then deposited on said substrate to form said film, said plasma including a cathode dark space having a first thickness;

positioning a plate element a first distance from said sputtering surface, said first distance being less than said first thickness and said plate element including a bottom surface and at least one edge;

inhibiting plasma formation in a first area adjacent said bottom surface by absorbing electrons emitted from said target such that target material is not eroded from a predetermined first portion of said sputtering surface opposite said first area;

forming plasma in a second area adjacent said edge to cause target material to be eroded from a predetermined second portion of said sputtering surface opposite said second area, thereby forming a desired non-uniform erosion pattern on said sputtering surface for improving thickness uniformity of said film.

9. The method according to claim 8, wherein said plate includes at least one hole to form first and second edges.

10. The method according to claim 8, wherein said plate element includes at least two concentric rings.

11. The method according to claim 8, wherein said plate element is a solid plate.

12. The method according to claim 8, wherein said plate element is maintained at a potential which is positive relative to said target.

13 The method according to claim 8, wherein said plate element is grounded.

14 The method according to claim 8, wherein said first distance is between approximately 0.05 and 1.0 inches.

15. A sputtering system for depositing a thin film on a substrate, comprising:

an evacuatable chamber;

a target positioned within said chamber, said target including a sputtering surface,

biasing means for biasing said target to form a cathode element which emits electrons;

an anode element which includes said substrate, wherein said substrate is positioned opposite said cathode element in said chamber;

ionization means for ionizing a sputtering gas, in response to said electrons, to form a plasma for eroding target material from said sputtering surface which is then deposited on said substrate to form said film, said plasma including a cathode dark space having a first thickness wherein ionization does not occur; and

a plate element having first and second outer edges and at least one hole to form first and second inner edges and first and second bottom surfaces, said plate element being grounded and spaced apart from said sputtering surface by a first distance which is between approximately 0.05 and 1.0 inches and which is less than said first thickness, wherein electrons emitted from said target are absorbed by said plate element to selectively inhibit plasma formation in first areas adjacent said first and second bottom surfaces such that target material is not eroded from predetermined first portions of said sputtering surface opposite said first areas, and wherein plasma is formed in a second areas adjacent said first and second inner and outer edges to cause

target material to be eroded from predetermined second portions of said sputtering surface opposite said second areas, thereby forming a desired non-uniform erosion pattern on said sputtering surface for improving thickness uniformity of said film.

16 The system according to claim 15, wherein said plate element includes at least two concentric rings.

17. The system according to claim 15, wherein said plate element is a solid plate.

18. The system according to claim 15, wherein said plate element is maintained at a potential which is positive relative to said target.

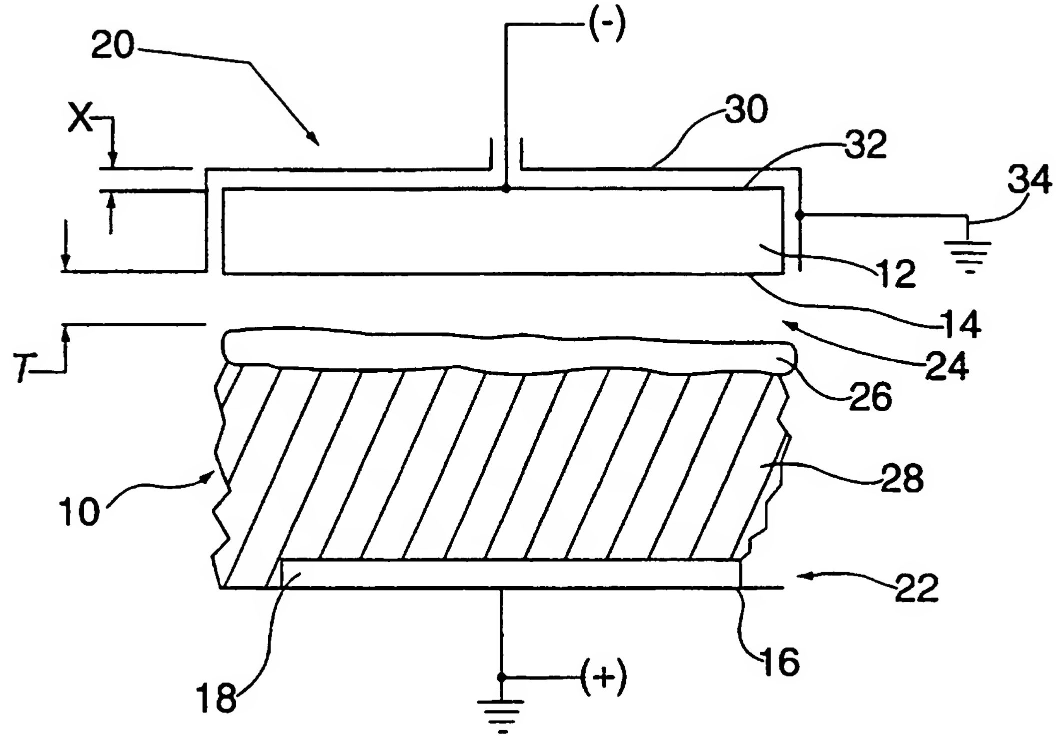
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FIG. 1

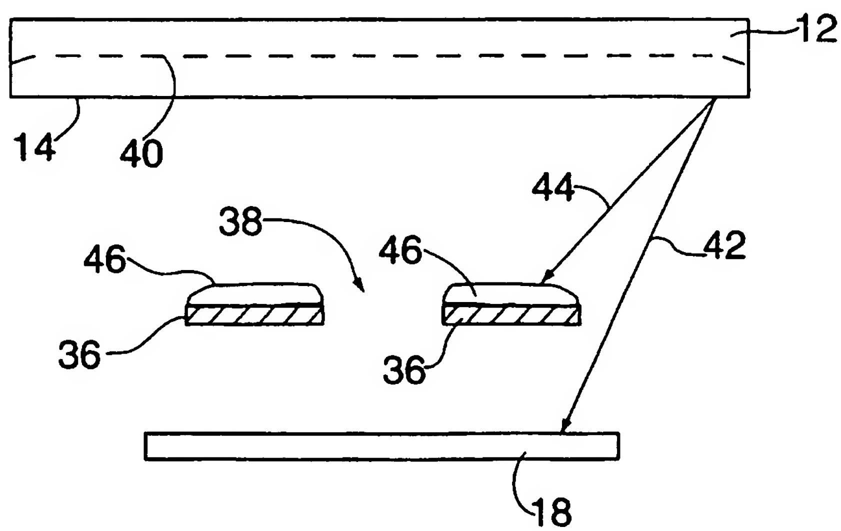
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FIG. 2

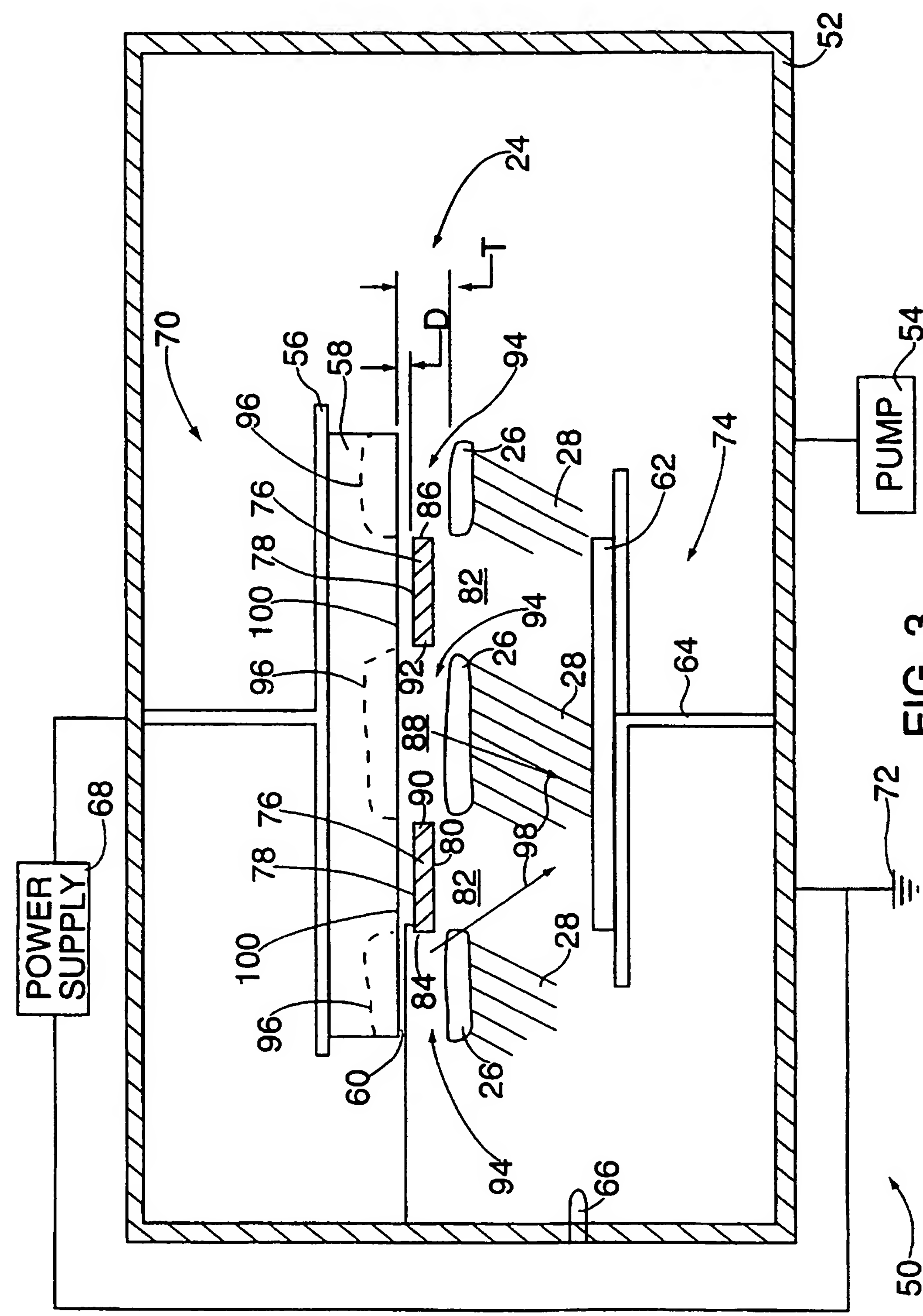

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :C23C 14/40
US CL : 204/192.12, 298.06, 298.11, 298.14, 298.15
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 204/192.12, 298.06, 298.11, 298.14, 298.15

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

None

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,824,544 A (MIKALESEN et al) 25 April 1989, Column 4 lines 64-68; Column 5 lines 1-5, lines 10-13, lines 54-65, lines 66-68; Column 6 lines 1-3.	1-18
Y	US 4,508,612 A (BLACKWELL et al) 02 April 1985, Column 3 lines 49-52; Column 5 lines 16-25, lines 26-36; Column 7 lines 21-27; Figure 2.	1-18
Y	US 3,985,635 A (ADAM et al) 12 October 1976, Column 2 lines 37-44, lines 45-50, lines 51-68; Column 3 lines 1-22, lines 60-63; Column 4 lines 18-23, lines 33-55; Column 6 lines 9-24.	1-18

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/03047

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3,361,659 A (BERTELSEN) 02 January 1968, Column 3 lines 50-57, lines 63-68; Column 4 lines 60-75; Column 5 lines 1-17, lines 27-30; Column 6 lines 32-34.	1-18